TABLE 18. PARTIAL DERIVATIVES FOR EQUATION 10

y = \ x =	$\partial x/\partial y$	
	ln U	ln Q
ln U	---	- 0.88
ln Q	= 1.14	---

If one wished to know the relationship between the unit depreciation and Q, one could formulate the following relationship:

$$U^{(2)} = U^{(1)} \left(Q^{(1)}/Q^{(2)}\right)^{1.14} \qquad (12)$$

If $Q^{(1)}$ and $U^{(1)}$ are 4 x 10^6 mil gal and \$117.65/mil gal, respectively, then if Q^2 increases to 4.5 x 10^6, $U^{(2)}$ = 103.01 for ACC to remain constant. Obviously, if U^2 increases, then ACC will increase.

For the water utilities studied, another relationship can be formulated that relates interest to depreciation. It is as follows:

$$I = 104.6\ D^{0.65} \qquad (13)$$

Equations 1 and 10 can be combined to yield an annual total cost equation, as shown below:

$$ATC = 20.13\ D_{mh}^{\ 0.69}\ M_{mg}^{\ 0.54}\ Q^{0.96} + 25.7\ (D/Q)^{0.74}\ Q^{0.84} \qquad (14)$$

It can be seen from Equations 1, 5, and 14 that if capacity is increased, the value for D/Q will increase accordingly, and ACC will rise at a more rapid rate than AOC. Therefore, when capacity is increased sharply the ratio of AOC to ACC will drop for a period of time and then increase gradually.

Equations 1, 10, and 14 give annual operating, capital, and total costs for the utilities studied and Table 19 provides a mechanism for assigning cost by individual cost category. For example, line 1 of Table 19 shows that 31% of the operating costs are associated with support services. Assuming that this percentage stays constant with changes in the independent variables, it can be used to estimate the proportion of annual cost that can be assigned to support services. Line 2 of Table 19 contains the percentages by cost category for capital costs.

TABLE 19. UTILITY COSTS BY CATEGORY

	Percent of Cost by Category				
Item	Support Services	Acquisition	Treatment	Power & Pumping	Transmission & Distribution
Operating cost	31	22	8	16	19
Capital cost	9.8	12.6	10.3	-	67.3

Production Related Costs

Another important cost relationship is between annual operating and capital costs and revenue-producing water. Table 20 summarizes these costs for acquisition, treatment, transmission and distribution, and support services, using the equation form

$$y = AQ^b \tag{15}$$

The operating cost data are the annual operating expenditures for a given cost category corrected to 1974, using the CPI. Capital costs are given as annual depreciation, also corrected to 1974. For example, it can be seen that both annual capital and operating costs for the utilities studied are increasing at an increasing rate for acquisition. This result implies that as the amount of revenue-producing water increases the utility must seek sources farther and farther away from the treatment plant, resulting in costs increasing at an increasing rate with Q. The results in Table 20 for treatment capital costs are somewhat different than might be expected from intuition. It is normally assumed that economies of scale exist with respect to treatment capacity ($b < 1$).

TABLE 20. RELATIONSHIP BETWEEN ANNUAL COST AND REVENUE-PRODUCING WATER*
(Corrected to 1974)

	Operating Cost** $C = aQ^b$			Capital Cost** $C = aQ^b$		
Item	a	b	r^2	a	b	r^2
Support services	141	0.95	0.94	3.61	1.06	0.76
Acquisition	2.1	1.23	0.64	2.4×10^{-8}	2.89	0.67
Treatment	4202	0.53	0.53	5.2	1.01	0.52
Transmission and Distribution	358	0.82	0.91	25.7	1.06	0.89
Total	621	0.91	0.93	28.7	1.09	0.89

* Power and pumping costs have been allocated into other cost categories.
** c = annual cost in dollars, a = constant, b = rate of change, Q = revenue-producing water in mil gal/yr.

The results reported in Table 20 are the annualized cost of capital (exclusive of interest) corrected to 1974, using the CPI. These costs include the effects of inflation over time. In Table 16 these effects are accounted for by the term e^{st}. Results from Table 20 confirm by their linearity that the unit cost of water has remained fairly constant when inflation has been removed. Two other factors influence the unexpected value for b. One is that the independent variable is revenue-producing water which is always less than design capacity. The second is that these costs include capital improvements and system add-on which may be more nearly linear in cost as compared to initial investments. As demand increased, it is often met by the addition of a relatively small facility, building block fashion. Adding increments of capacity in this manner over time no doubt eliminates some economies of scale in initial construction.

Equation 16 is a relationship between total chemical costs, and revenue-producing water and source quality:[12]

$$C_c = 25.50\ Q^{0.91}\ (1.91)^X \qquad (r^2 = 0.71) \qquad (16)$$

where C_c = Annual chemical costs corrected to 1974 dollars

Q = Revenue-producing water

X = 1 for poor quality surface source water; 0 for high quality ground or protected surface source water.

if X = 1, then

$$C_c = 48.6\ Q^{0.91} \qquad (17)$$

if X = 0, then

$$C_c = 25.5\ Q^{0.91} \qquad (18)$$

Equation 19 shows the relationship between annual power cost and revenue-producting water and head:

$$C_p = 154.3\ Q^{0.77}\ (1.34)^{X_1}\ (1.23)^{X_2} \qquad (r^2 = 0.90) \qquad (19)$$

where C_p = Annual power cost in 1974 dollars

Q = Revenue-producing water

X_1 and X_2 = Dummy variables such that: $X_1 = 1$, $X_2 = 1$ are the conditions for high head pumping above 700 ft.; $X_1 = 1$, $X_2 = 0$ are conditions for medium elevation pumping 300 - 700 ft; $X_1 = 0$, $X_2 = 0$ are the conditions for low head pumping 0 - 300 ft.

For example, if $X_1 = 1$, $X_2 = 1$ then

$$C_p = 349.2\ Q^{0.78} \qquad (20)$$

if $X_1 = 1$, $X_2 = 0$ then

$$C_p = 283.9\ Q^{0.78} \qquad (21)$$

and if $X_1 = 0,\ X_2 = 0$ then

$$C_p = 154.3\ Q^{0.78} \tag{22}$$

Cincinnati, Ohio, might provide an example of how the equation might be used. Cincinnati draws water from the Ohio River which is a poor quality surface source and water is pumped to high elevations. Therefore equations 17 and 20 would be used to estimate chemical and power costs.

<u>Costs as a function of spatial and demographic variables</u> -- A relationship that might be useful to many water works managers is one between unit cost and selected physical and/or demographic variables. Column 2 of Table 21 contains the incremental costs for the Cincinnati cost zones shown in Figure 24, Treatment, acquisition interest, and support services costs have been removed. Column 3 is the straight line distance from the treatment plant to the centroid of each zone, Column 4 contains the elevation at the centroid relative to the treatment plant, and Column 5 is the population density in each zone, Eq 23 expresses the relationship between unit incremental cost, population density, and distance. The equation is as follows:

$$C_u = 122.0\ P_d^{-0.65}\ D_i^{0.20} \qquad (r^2 = 0.76) \tag{23}$$

where C_u = Unit incremental cost in \$/mil gal

P_d = Population density in thousand people/sq mi

D_i = Distance to the cost zone centroid in mi

If P_d were constant at $\overline{P}_d$, then the rate of change of incremental cost is given as shown below:

$$\frac{\partial C_u}{\partial D_1} = K_1\ D_i^{-0.80} \tag{24}$$

where $K_1 = 24.4\ \overline{P}_d^{-0.65}$

As can be seen from Eq 24, unit cost increases at a decreasing rate with distance, assuming constant population density. If distance were held constant at $\overline{D}_i$, then the rate of change of cost with respect to P_d is as follows:

$$\frac{\partial C_u}{\partial P_d} = K_2\ P_d^{-1.65} \tag{25}$$

where $K_2 = -79.3\ (\overline{D}_i)^{0.20}$

TABLE 21. INCREMENTAL COSTS AND ASSOCIATED STATISTICS FOR CINCINNATI WATER WORKS SERVICE AREA

Zone	Incremental Cost ($/mil gal)*	Distance to Zone Centroid (mi) **	Elevation of Centroid (ft)+	Population Density (thou people/sq mi)**
A	198.44	0.5	0.0	,384
B1	130.80	3.7	221.7	1.324
B2	271.54	6.2	325.8	.839
C1a	56.98	9.7	174.9	2.656
C1b	238.83	17.3	338.9	.674
C2	66.74	12.7	140.2	4.697
C3a	69.48	9.6	168.5	6.730
C3b	140.36	16.5	339.1	1.896
C4a	58.50	10.3	11.5	5.358
C4b	173.54	13.9	310.7	2.736

* 1 $/mil gal = 0.26 x 10^{-9} $/m^3$

** 1 mile = 1610.4 meters

\+ 1 ft = 0.91 meters

++ 1 person/sq mi = 3.874 x 10^{-7} thou people/m^2

As can be seen from Eq 25, the unit cost decreases at a decreasing rate with increasing population density. Taking the natural log transform of Eq 22 and differentiating and setting each partial differential equal to zero yields that data in Table 22.

TABLE 22. PARTIALS FOR NATURAL LOG TRANSFORM OF EQUATION (22)

	$\partial y/_{\partial y}$	
y = \ x =	$\ln P_d$	$\ln D_i$
$\ln P_d$	-	0.31
$\ln D_i$	3.25	-

From Table 22 we see that for the cost to stay constant $\left(\frac{\partial C_u}{\partial D_i} = \frac{\partial C_u}{\partial P_d} = 0\right)$ the following relationship must hold:

$$\frac{D_i^{\,1}}{D_i^{\,2}} = \left(\frac{P_d^{\,1}}{P_d^{\,2}}\right)^{0.31} \tag{26}$$

If $D_i^{\,2}$ is farther away from the treatment plant than $D_i^{\,1}$, then population density must increase in accordance with Eq 26 for $\frac{\partial C_u}{\partial D_i}$ to remain constant. Generally, population density decreases with distance from the treatment plant leading to increases in unit cost due to decreasing density and increasing distance.

Another relationship that can be developed from the data in Table 21 is shown below:

$$E = 1.8\ D_i^{\,1.4} \quad (r^2 = 0.60) \tag{27}$$

where E = Elevation of the cost zone in feet above the treatment plant and D_i = Radial distance to the centroid of a cost zone in mi from treatment plant.

The general topography of the Cincinnati service area verifies the accuracy of Eq 26

Eq 26 demonstrates that the incremental cost of transporting increases with distance. Assume the following:

$$C_t = \text{total cost for transporting water} \tag{28}$$

$$P_d = K \text{ (a constant)} \tag{29}$$

$$Q = \alpha D_i \text{ (water transmitted increases with distance)} \tag{30}$$

$$C_u = \frac{C_t}{Q} \tag{31}$$

or

$$C_u = \frac{C_t}{\alpha D_i} \tag{32}$$

Substituting eq 29 and 32 into eq 23 and collecting terms yield

$$C_t = 122\alpha K\ D_i^{1.20} \tag{33}$$

Since $122\alpha K$ is constant, then C_t increases with D_i.

It can also been seen from Eq 26 that, for the Cincinnati utility, unit cost increases with distance from the treatment plant and decreases with population density. Neither of the conclusions is surprising, but Eq 22 quantifies this relationship. Eq 27 shows that, for the Cincinnati utility, elevation tends to increase fairly regularly with distance from the treatment plant. Eq 23 through 33 lead to the conclusion that there may be definite limitations of the economically efficient size of a utility service area. Recognized economies of scale are offset by diseconomies of scale due to the distance water must be transported. The equations developed herein may be useful to define the most efficient system size. Once costs exceed a given value, managers and planners should consider establishing a new treatment plant if an adequate source is available. These kinds of relationships might also prove useful to the manager when making pricing decisions.

SECTION 8

COST OF IMPLEMENTING THE SAFE DRINKING WATER ACT

The previous analysis shows that water supply costs are increasing (see Figures 62 through 73). Some of these increases are due to pressure from increased consumption, and others are the results of inflationary effects. Equation 1 establishes a relationship between $/man-hour ($D_{mh}$), man-hours/mil gal ($M_{mg}$), and production of revenue-producing water (Q) Costs for D_{mh} are heavily dependent on inflation, while costs resulting from increases in Q are more nearly related to increases in demand. Productivity in man-hours/mil gal is dependent to a large degree on management policy.

By studying the trends in water supply costs, it is possible to understand some of the economic impacts of the Safe Drinking Water Act. In the following section, historic trends will be utilized to estimate expected increases in cost. Hypothetical requirements for the proposed organic regulations in the Safe Drinking Water Act will be superimposed on these expected increases. It will be possible to separate the expected cost increases from those associated with the Safe Drinking Water Act.

TRENDS IN WATER SUPPLY

The trends established in the previous sections for a 10-year time period will be assumed in this analysis. For example, Figure 74 shows the average revenue-producing water pumped for all 12 utilities for a 10-year period ending 1974. This trend has been extrapolated through 1985. Revenue-producing water in 1974 was 32.8 billion gallons and, according to the extrapolation, will be 45.0 billion gallons in 1985 -- a 30% increase. This means an increase from a 93 mil gal/day system to a 121 mil gal/day system. Figures 75 through 78 show trends in operating and capital costs for the functional cost areas discussed earlier.

Table 23 summarizes average 1974 costs and projected average 1984 costs for all 12 utilities. The changes shown are expected changes, based on demand and inflationary pressures. Incremental costs above these expected costs resulting from the Safe Drinking Water Act will be analyzed in the following section.

IMPACT OF THE SAFE DRINKING WATER ACT

Calculations are based on the assumption that Safe Drinking Water Act control technologies will be installed by 1980. Three types of technology will be considered: granular activated carbon (GAC) with contactors, GAC

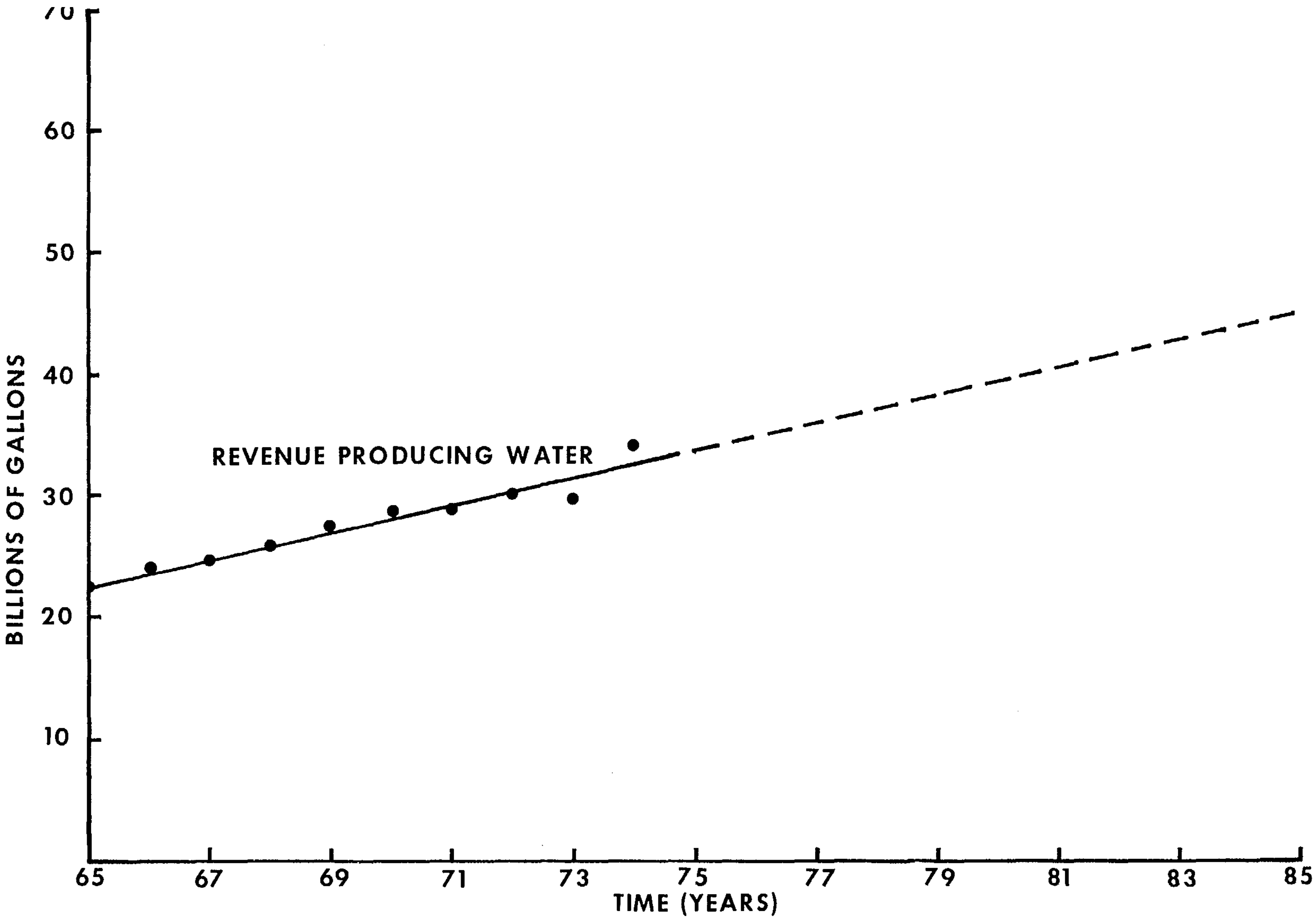

FIG. 74 REVENUE PRODUCING WATER EXTRAPOLATED OVER TIME

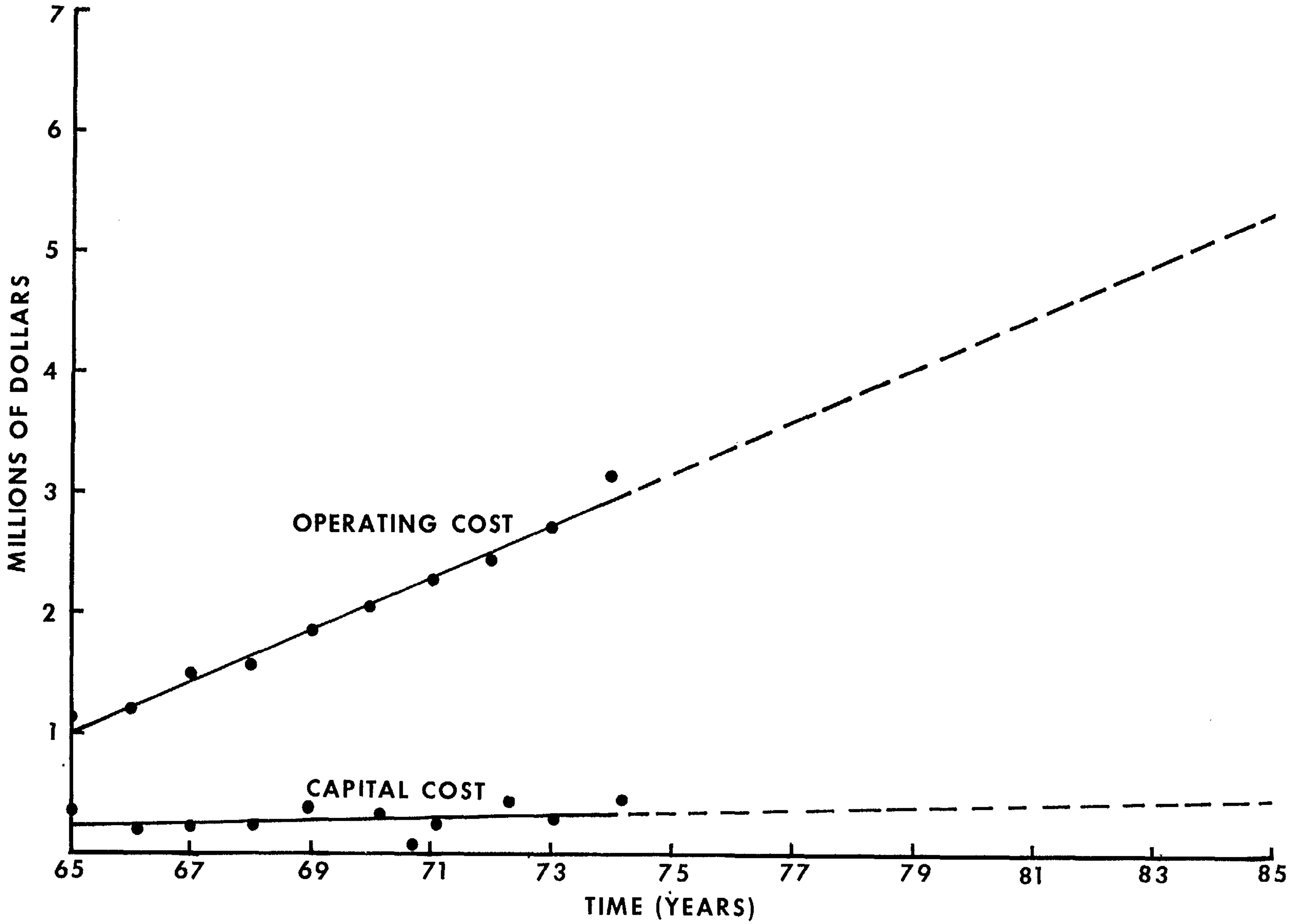

FIG. 75 SUPPORT SERVICES OPERATING AND CAPITAL COSTS EXTRAPOLATED OVER TIME

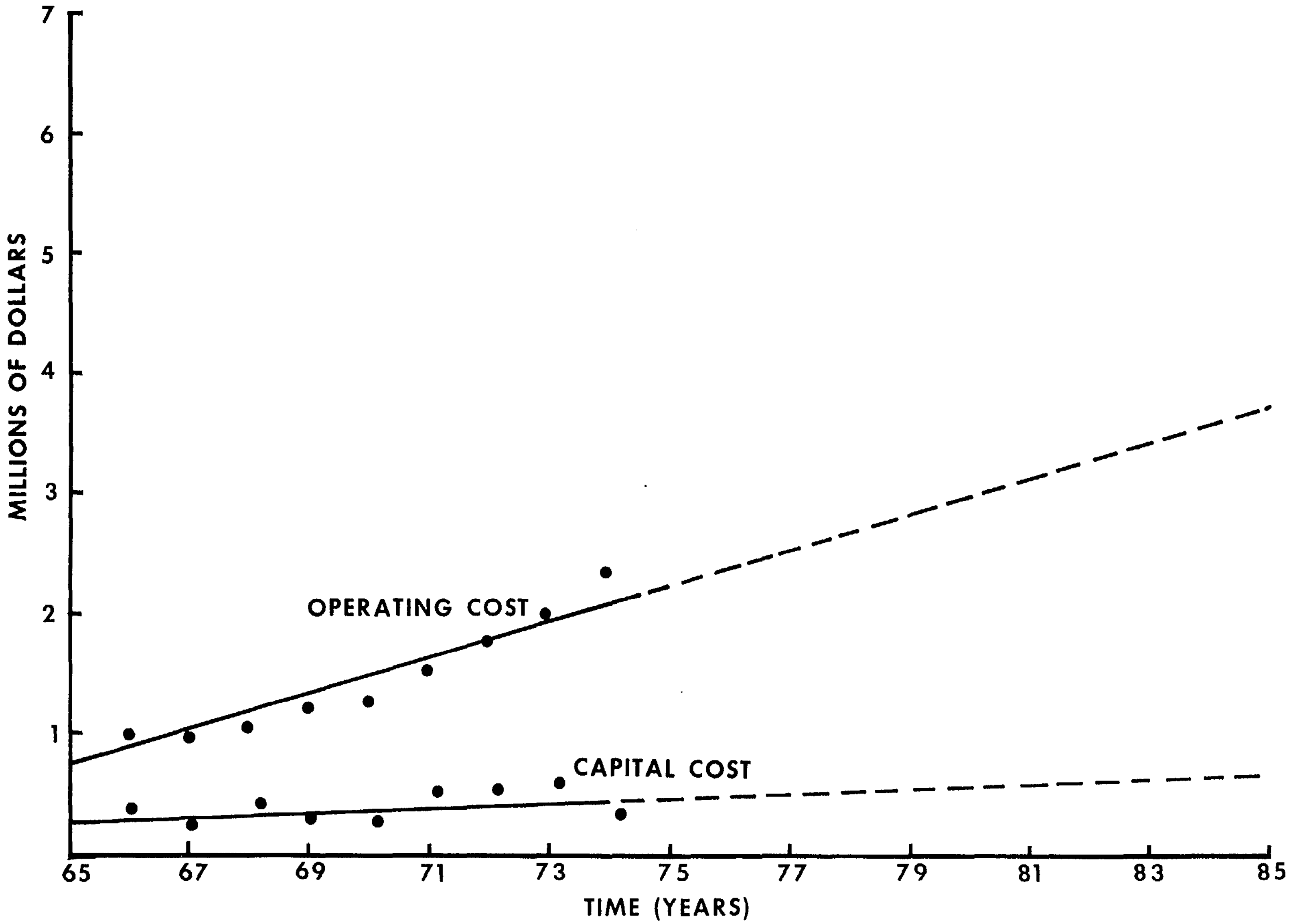

FIG. 76 ACQUISITION OPERATING AND CAPITAL COSTS EXTRAPOLATED OVER TIME

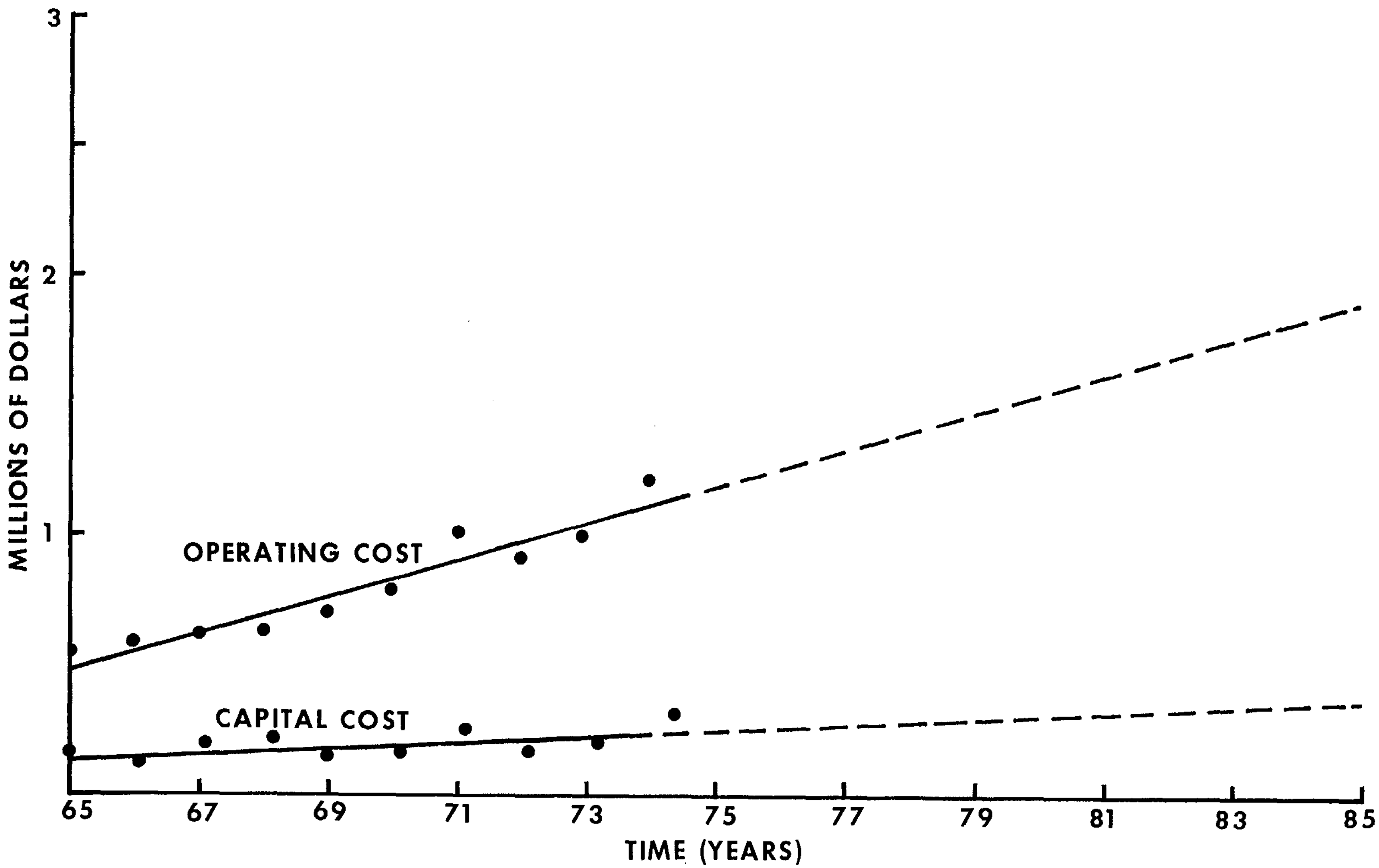

FIG. 77 TREATMENT OPERATING AND CAPITAL COSTS EXTRAPOLATED OVER TIME

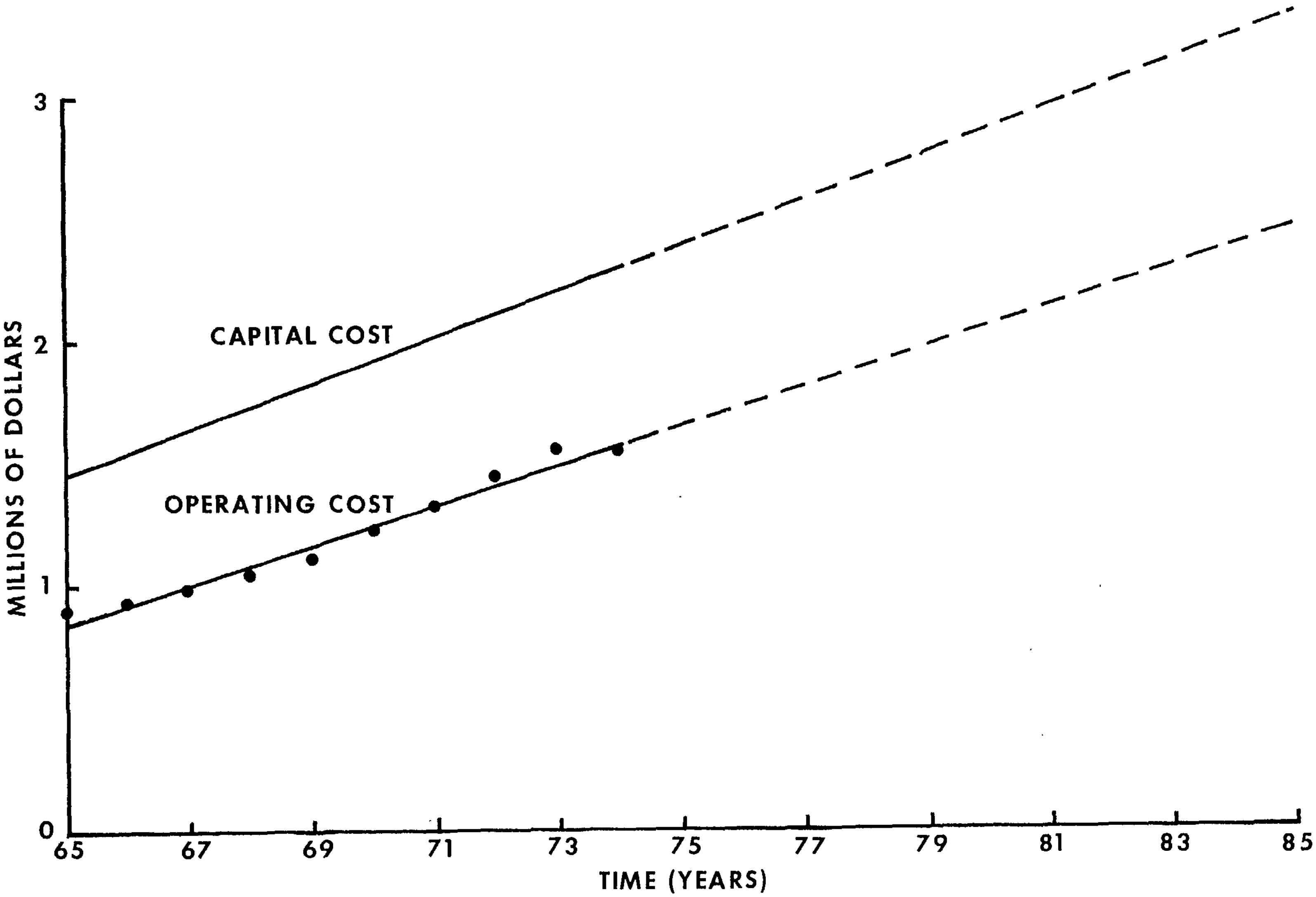

FIG. 78 TRANSMISSION AND DISTRIBUTION OPERATING AND CAPITAL COSTS EXTRAPOLATED OVER TIME.

TABLE 23. CURRENT AND PROJECTED AVERAGE EXPENSES FOR ALL 12 UTILITIES

Item	Cost		% Change
	1974	1984	
Total operating cost ($, millions/year)	8.81	14.8	+ 68
Total capital cost ($, millions/year)	3.8	5.7	+ 50
Total production cost ($, millions/year)	12.6	20.5	+ 63
Total unit cost ($/mil gal)	430	560	+ 30
Man-hours/mil gal	29.0	24.8	- 15
$/Man-hour	4.7	7.2	+ 53
Depreciation $/mil gal)	63.0	67.5	+ 7

replacing sand in the filter shell, and chlorine dioxide. From the previous analysis we learned that by the year 1984 our average utility will produce 120 MGD. It will therefore be assumed that any new treatment processes will be designed for a peak capacity of 150 MGD. Unit costs for each of the three technologies are shown in Table 24.

Figure 79 shows the CPI for the 10 years of analysis and for an additional 10 years, extrapolated in two ways. Based on conservative or straight line assumption, the CPI in 1980 is 1.9 (1965 = 1.0). Direct application of the conservative CPI to the 1975 unit costs yields the unit costs shown in the last two columns of Table 24. The new unit costs have been converted to annual costs and added to the expected treatment operating and capital costs in 1980, as shown in Figures 80 and 81. Beyond 1980 it is assumed that these incremental costs will be additive and at the same slope as the expected operating and capital costs. Figures 80 and 81 show that the adoption of GAC technologies will substantially increase treatment costs for the average water supply utility. Aggregating treatment costs with total capital and operating costs for the composite utility yields Figures 82 and 83. The percent increase in operating costs is much less than the percent increase in treatment cost alone. The impact on total production cost is shown in Figure 84, and the effect on unit cost is shown in Figure 85. Table 25 summarizes these cost increases.

Table 25 shows that the total production cost of water will increase by 36% between 1974 and 1980 without add-on technology. With the most expensive technology, total production costs will increase by 24% over those expected as a result of other pressures. Unit costs will increase by 24%.

The less conservative assumption regarding the increase in CPI would increase the add-on technology costs as shown in Figures 86 and 87. The increase in total water production cost, for example is 32%, and there is a 29% increase in unit cost.

The Effect of Time on Rate Structure - Without SDWA

As can be seen from the previous analysis, operating and maintenance costs will tend to dominate the cost of water supply over time due to the effects of inflation. Using data from all 12 utilities, we can formulate the following relationships for O&M and capital cost (Table 16):

$$OC = 360.4\, Q^{0.91}\, e^{0.056t} \qquad (r^2 = 0.93) \tag{34}$$

$$CC = 193.8\, Q^{0.91}\, e^{0.043t} \qquad (r^2 = 0.86)$$

where OC = Annual operating cost in dollars

CC = Annual capital cost in dollars

Q = Annual revenue-producing water in mil gal/yr

t = Relative time starting with year 1

TABLE 24. UNIT COSTS FOR CONTROL TECHNOLOGY AT 150 MGD*[13]

Treatment Technology	Unit cost, 1975 ($/1,000 gallons)		Unit cost, 1980 ($/1,000 gallons)	
	Capital	Operating	Capital	Operating
Chlorine dioxide	0.2	1.0	0.24	1.22
Granular activated carbon (contactors)	4.1	2.2	5.00	2.68
Granular activated carbon (Media replacement)	1.1	4.0	1.34	4.88

* Costs are calculated at 70% of capacity.

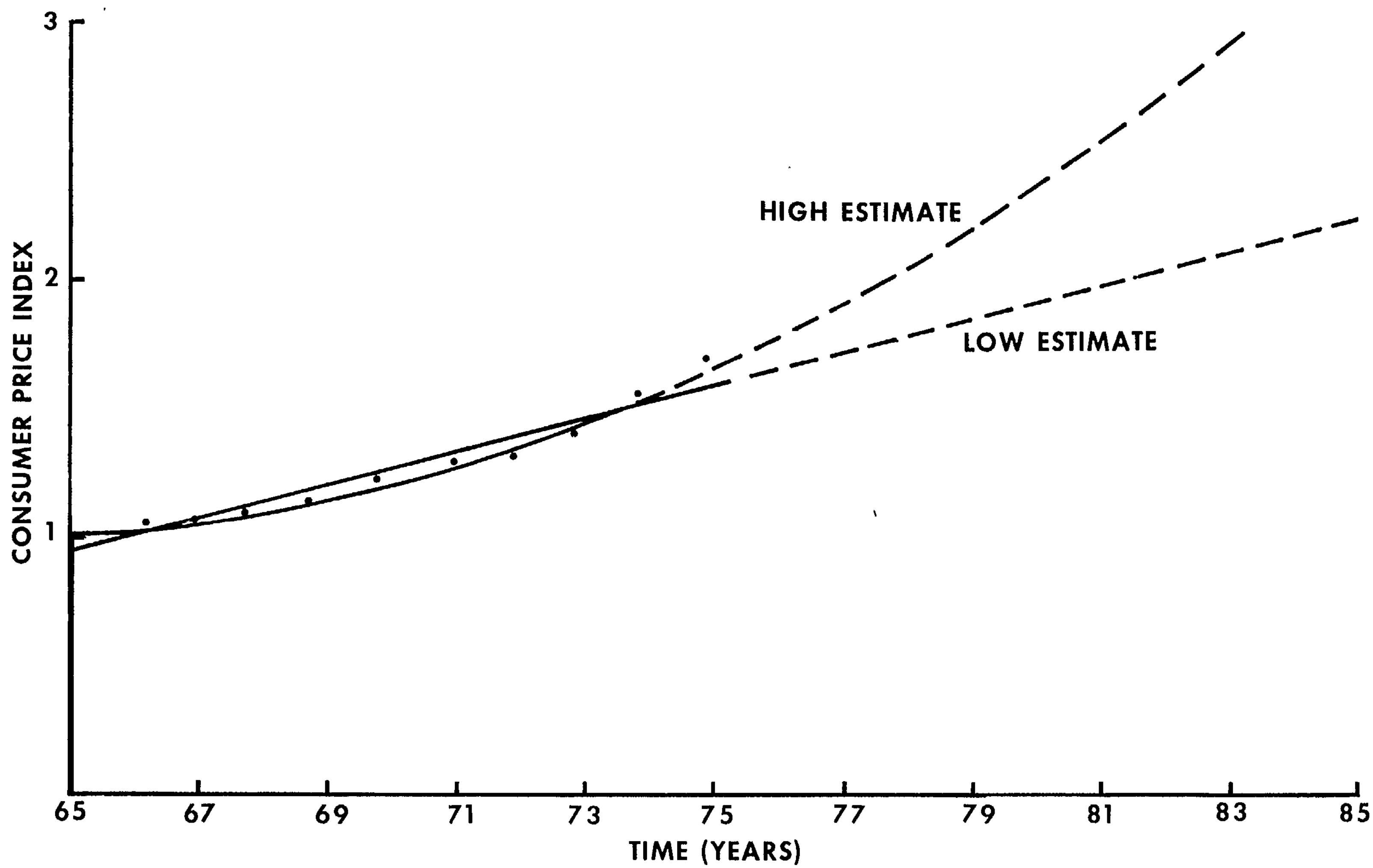

FIG. 79 CPI EXTRAPOLATED OVER TIME

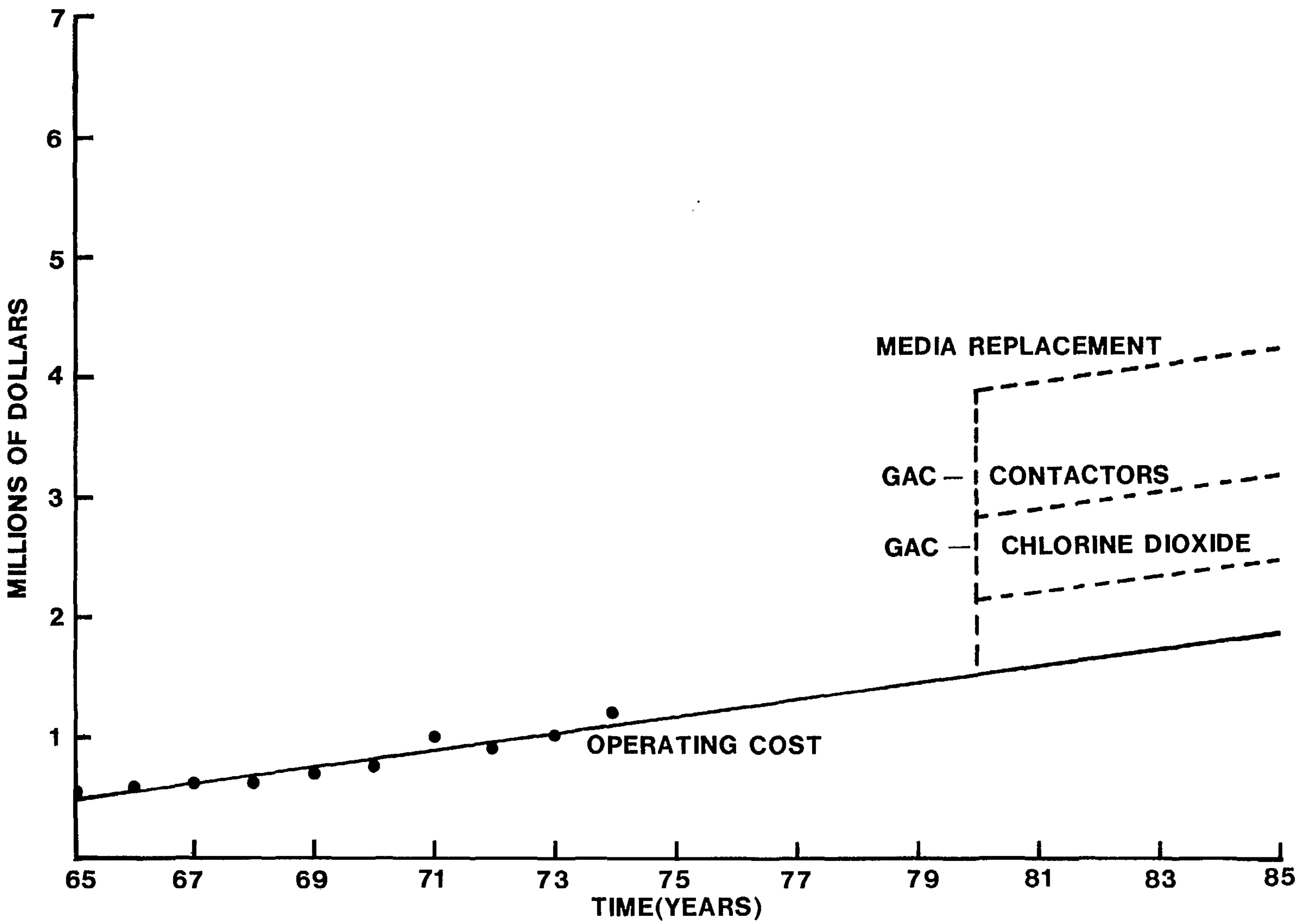

FIG. 80 TREATMENT OPERATING COSTS EXTRAPOLATED TO INCLUDE CONTROL TECHNOLOGY

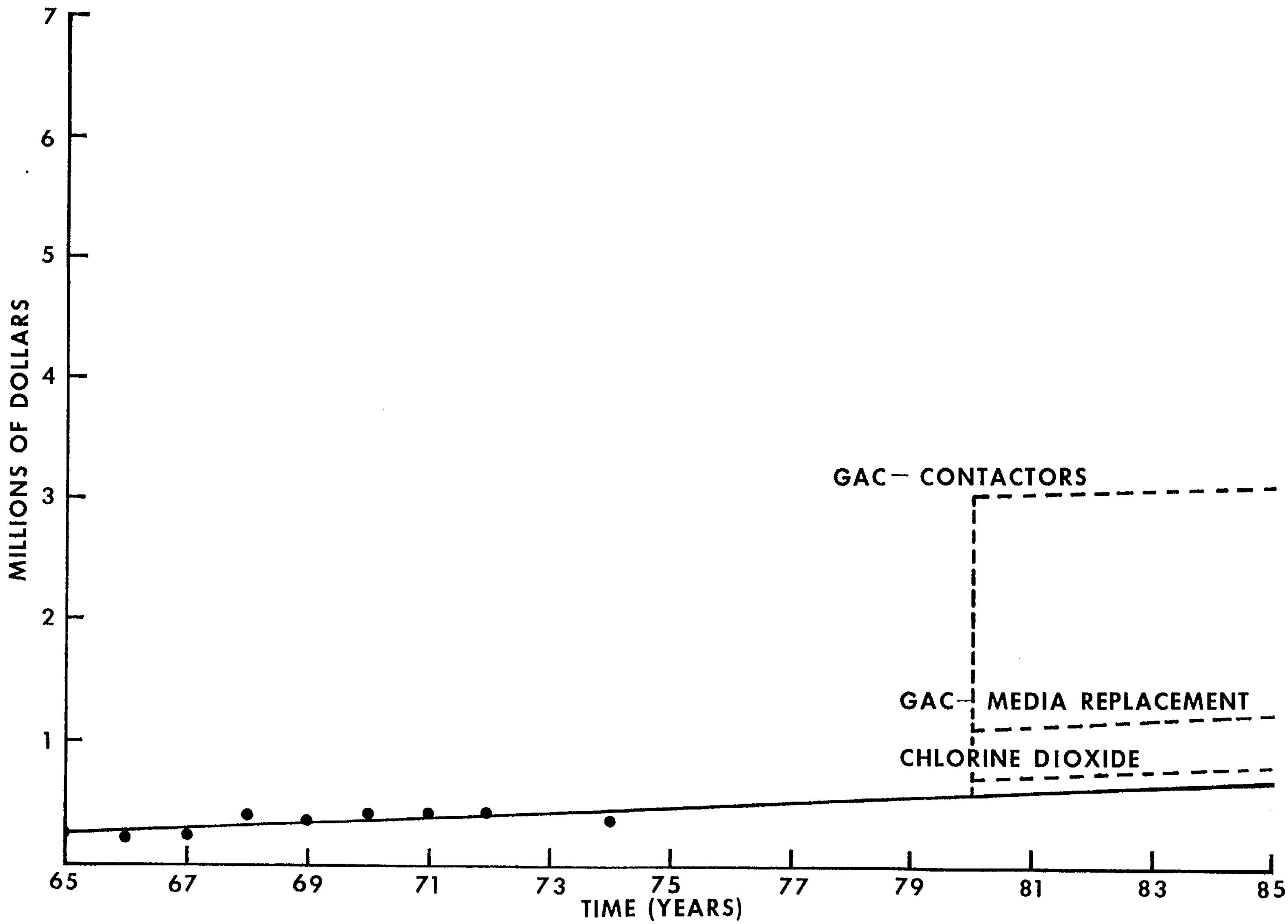

FIG. 81 TREATMENT CAPITAL COSTS EXTRAPOLATED TO INCLUDE CONTROL TECHNOLOGY

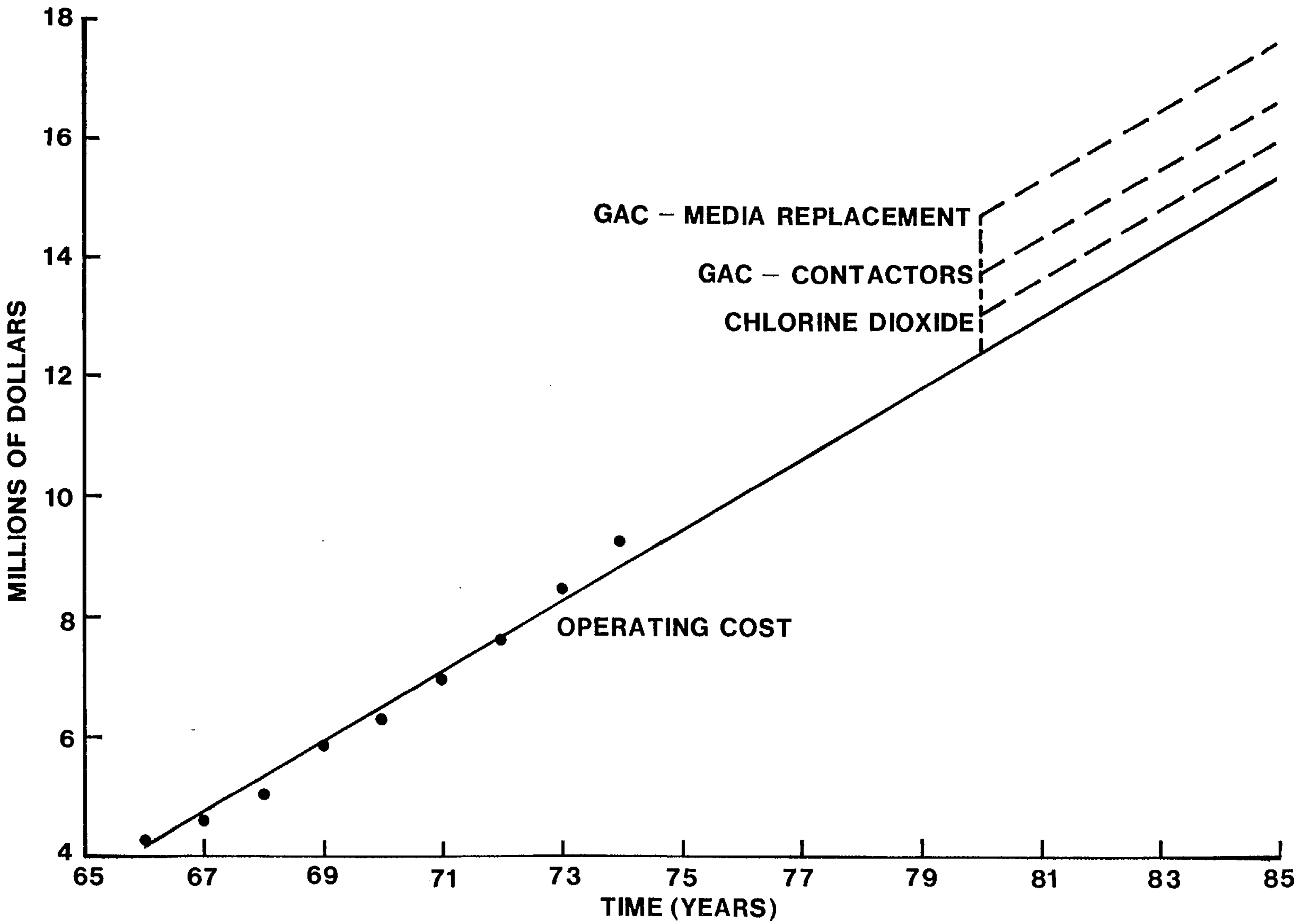

FIG. 82 TOTAL OPERATING COST EXTRAPOLATED TO INCLUDE CONTROL TECHNOLOGY OPTIONS

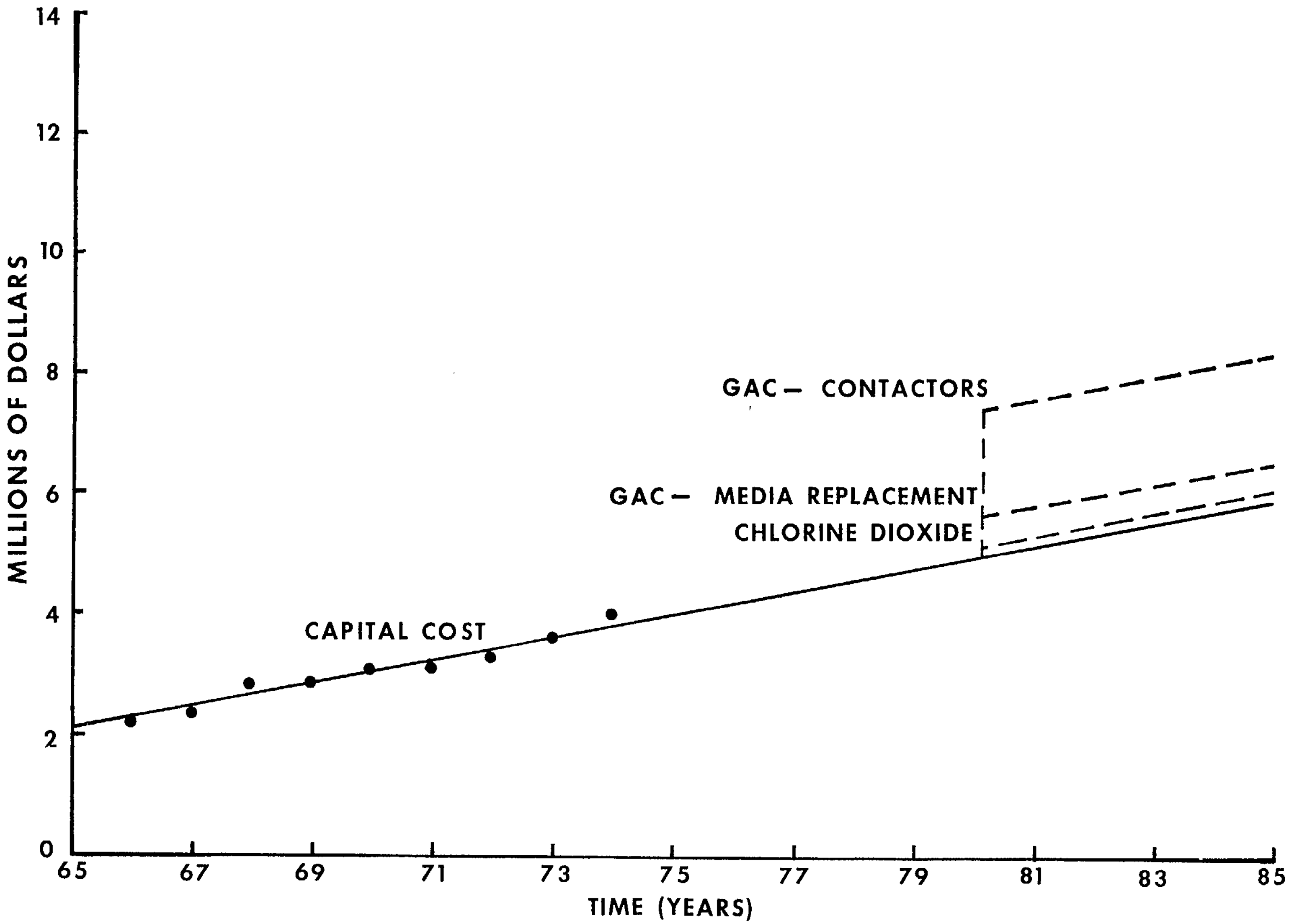

FIG. 83 TOTAL CAPITAL COST EXTRAPOLATED TO INCLUDE CONTROL TECHNOLOGY OPTIONS

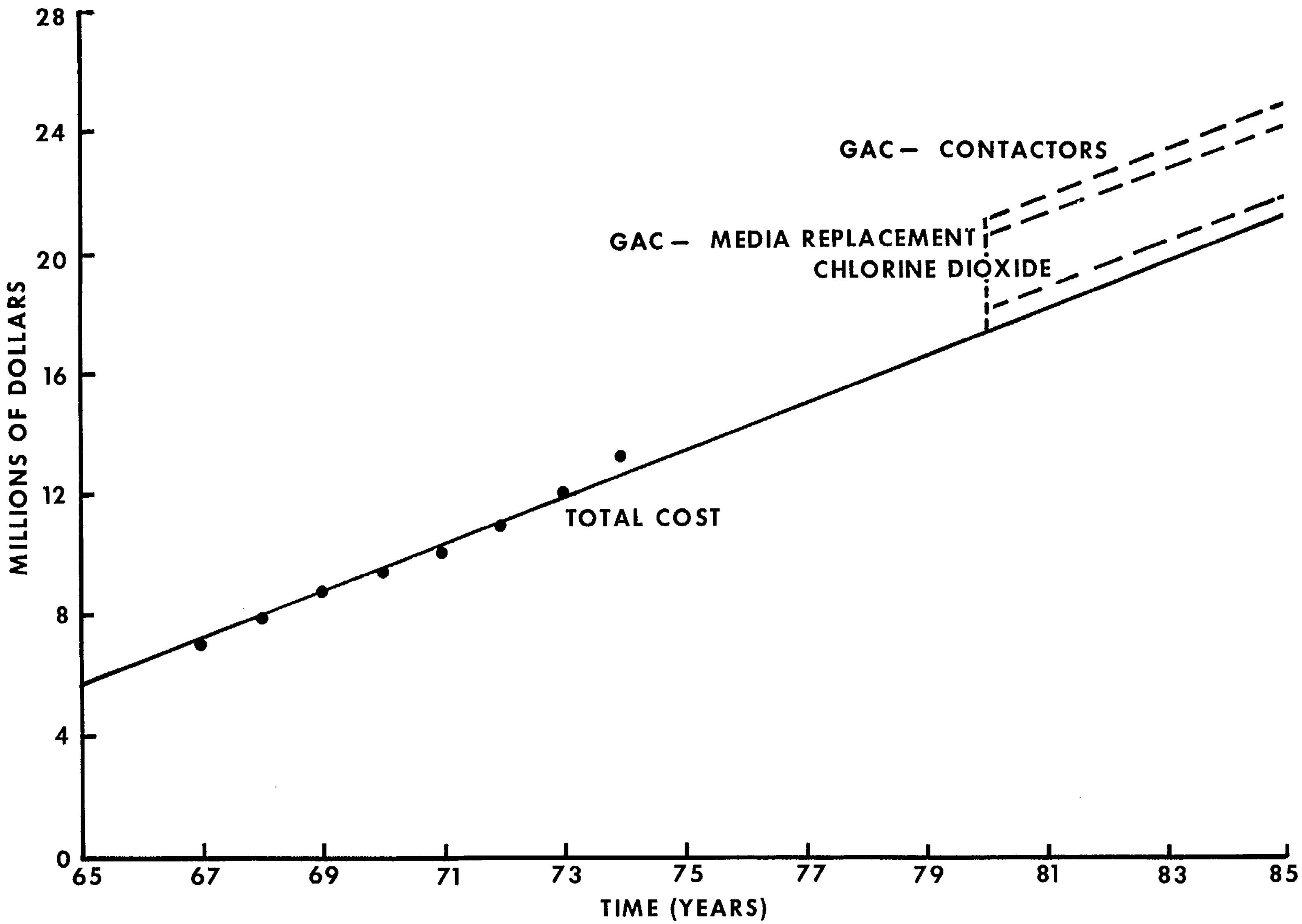

FIG. 84 TOTAL COST EXTRAPOLATED TO INCLUDE CONTROL TECHNOLOGY OPTIONS

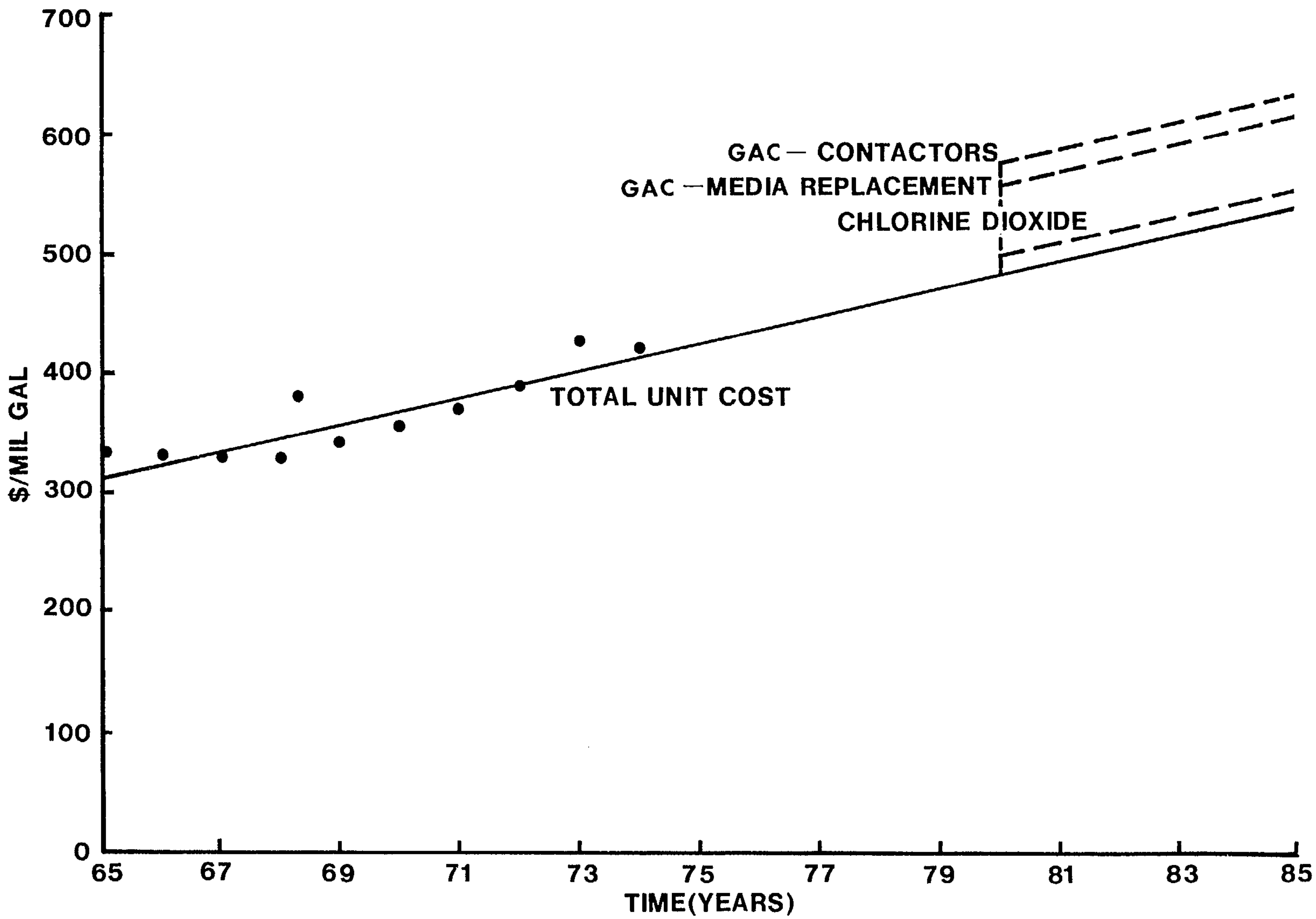

FIG. 85 TOTAL UNIT COST EXTRAPOLATED TO INCLUDE CONTROL TECHNOLOGY OPTIONS

TABLE 25. EXPECTED COSTS IN 1980 FOR AN AVERAGE UTILITY

Item	Cost in 1975	Expected cost in 1980	Expected 1980 costs with add-on technologies		
			GAC -- contactors	GAC -- media replacement	Chlorine dioxide
Treatment operating cost (($/millions/year)	1.10	1.50	2.97	4.17	2.17
Treatment capital cost ($, millions/year)	0.48	0.60	3.34	1.33	0.73
Total operating cost ($, millions/year)	8.85	12.40	13.87	15.07	13.07
Total capital cost ($, millions/year)	3.80	4.95	7.69	5.68	5.08
Total production cost ($, millions/year)	12.75	17.35	21.56	20.75	18.25
Total unit cost ($/mil gal)	412.00	480.00	596.47	574.06	504.90

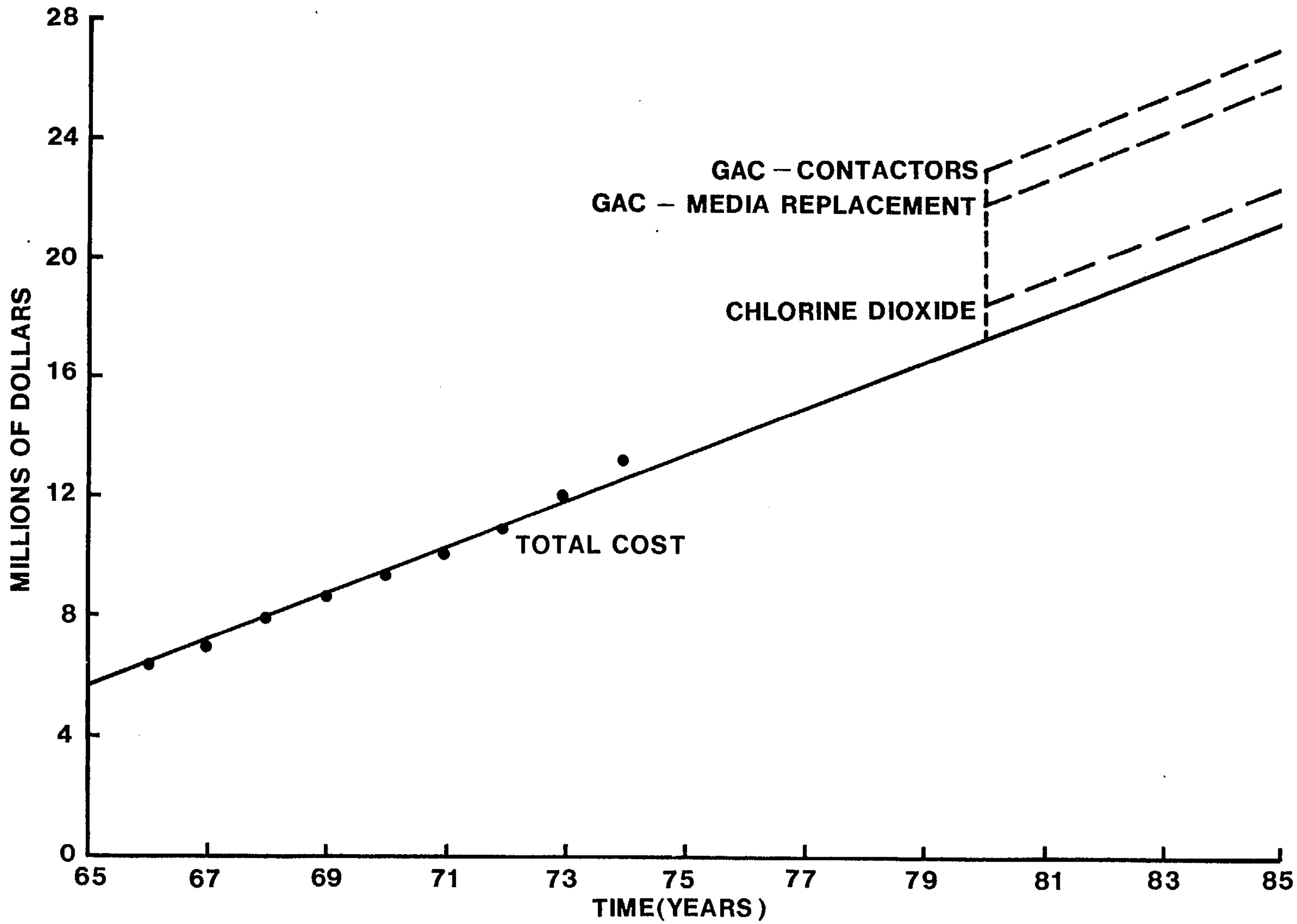

FIG. 86 TOTAL COST EXTRAPOLATED TO INCLUDE CONTROL TECHNOLOGY OPTIONS: HIGH ESTIMATE

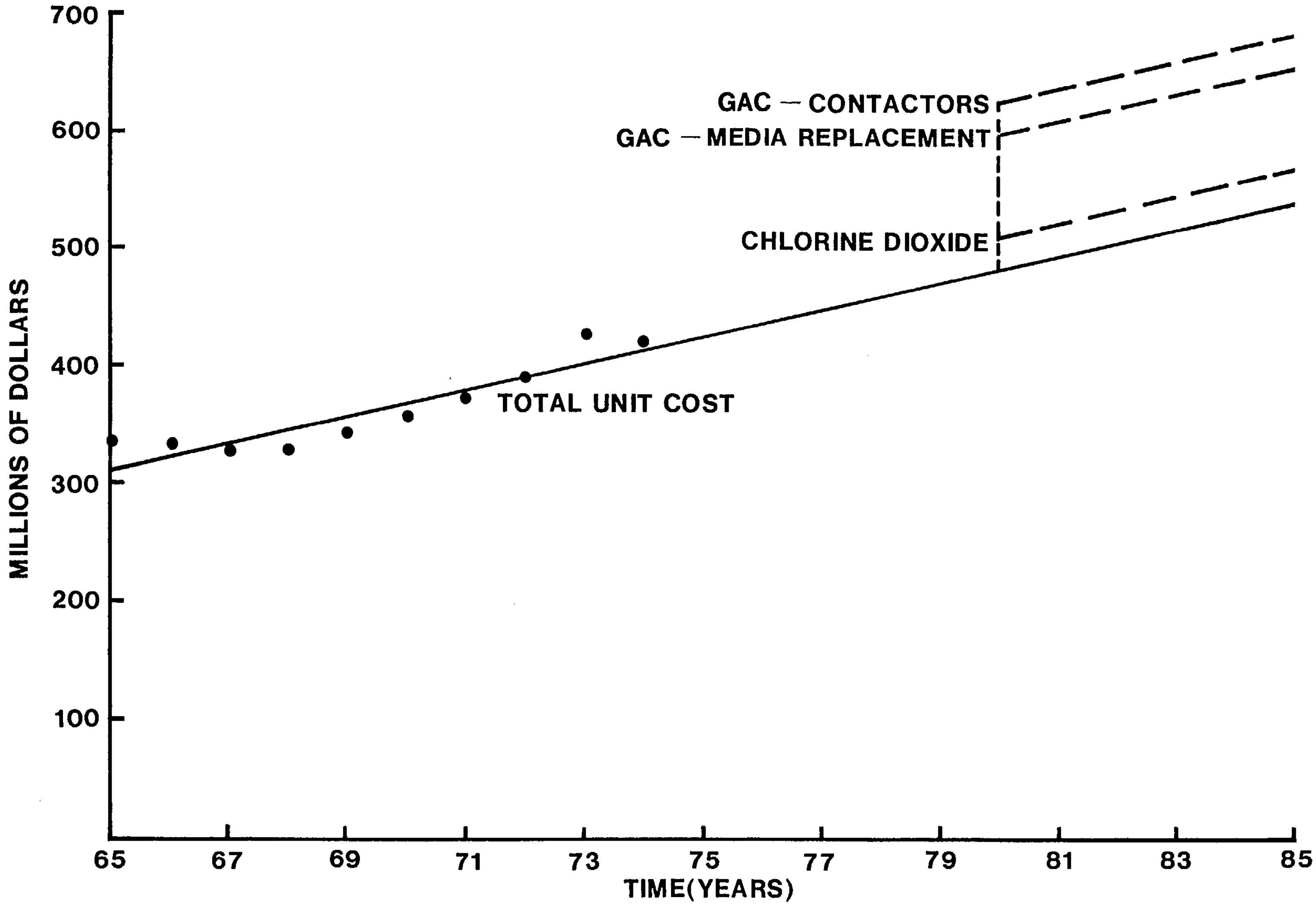

FIG. 87 TOTAL UNIT COST EXTRAPOLATED TO INCLUDE CONTROL TECHNOLOGY: HIGH ESTIMATES

By formulating the ratio between operating cost and capital cost (Equations 34 and 35) we see the following:

$$\frac{OC}{CC} = 1.86\ e^{0.013t} \tag{36}$$

From Equation 36 it can be seen that in terms of cost and ultimately the rate structure, water supply costs will be increasingly dominated by operating expenditures.

The Effect of Time on Rate Structure - With SDWA

Assume Equations 31 and 32 are the new capital cost equation and operating cost equation as shown below:

$$OC_n = 427.25\ Q^{0.91}\ e^{0.056t} \tag{37}$$

$$CC_n = 219.64\ Q^{0.91}\ e^{0.043t} \tag{38}$$

Forming the ratio of Equation 37 to Equation 38 yields

$$\frac{OC_n}{CC_n} = 1.95\ e^{0.013t} \tag{39}$$

As can be seen from Equations 39 and 36, in a short period of time the new capital requirements resulting from the Safe Drinking Water Act will be insignificant when compared to total operating expenditures.

APPENDIX

The appendix contains regression equations for items of interest for each of the utilities studied. Time in the equations is in calendar years rather than in relative time.

APPENDIX

Cost equations are given for individual utilities over time. Both linear and exponential equations are presented.

TABLE A-1. ANNUAL OPERATING COST VERSUS TIME

Utility	Linear* $C = b + mt$ b	m	r^2	Exponential+ $C = Ke^{bt}$ K	b	r^2
Fairfax Co.	-2.94×10^7	464000	0.96	1.3	0.21	0.86
Elizabethtown	-4.40×10^7	765000	0.86	29000.	0.08	0.92
Kansas City	-2.93×10^7	521000	0.95	29000.	0.08	0.92
Pueblo	-6.32×10^6	114000	0.76	13000.	0.07	0.86
New Haven	-1.43×10^7	252000	0.97	10400.	0.08	0.97
Cincinnati	-2.56×10^7	472000	0.96	62500.	0.07	0.97
San Diego	-9.38×10^7	1.56×10^6	0.88	7700.	0.11	0.92
Orlando	-1.34×10^7	219000	0.90	370.	0.12	0.97
Dallas	-4.94×10^7	836000	0.94	10200.	0.10	0.97
Kenton Co.	-1.93×10^6	33900	0.92	1742.	0.08	0.97
Seattle	-2.96×10^7	517000	0.97	18300.	0.08	0.97
Phoenix	-4.68×10^7	791000	0.91	9712.	0.10	0.97

* C = annual cost in $/year
b = constant
m = slope
t = calendar year

\+ C = annual cost in $/year
K = constant
b = rate of change
t = calendar year

TABLE A-2. ANNUAL CAPITAL COST VERSUS TIME

Utility	Linear* $C = b + mt$			Exponential+ $C = Ke^{bt}$		
	b	m	r^2	K	b	r^2
Fairfax Co.	-4.33×10^7	690000	0.39	0.07	0.26	0.46
Elizabethtown	-2.44×10^7	404000	0.91	1285.	0.11	0.92
Kansas City	-3.97×10^6	88000	0.66	171000.	0.04	0.66
Pueblo	-6.54×10^6	108000	0.51	701.	0.10	0.66
New Haven	-2.68×10^7	447200	0.91	1695.	0.11	0.94
Cincinnati	994000	20500	0.10	1.31×10^6	0.01	0.10
San Diego	4.38×10^6	18200	0.06	4.70×10^6	0.01	0.06
Orlando	5.05×10^6	90759	0.53	11400.	0.07	0.53
Dallas	-2.52×10^7	448000	0.40	34200.	0.07	0.23
Kenton Co.	604000	10900	0.30	2037.	0.06	0.41
Seattle	-3.60×10^6	95900	0.91	353000.	0.03	0.93
Phoenix	1.18×10^7	18100	0.92	38300.	0.06	0.97

* C = annual cost in $/year
b = constant
m = slope
t = calendar year.

\+ C = annual cost in $/year
K = constant
b = rate of change
t = calendar year.

TABLE A-3. REVENUE-PRODUCING WATER VERSUS TIME

Utility	Linear* $C = b + mt$ b	m	r^2	Exponential+ $C = Ke^{bt}$ K	r	r^2
Fairfax Co.	150000	2352	0.74	0	0.31	0.69
Elizabethtown	13200	680	0.52	8395.	0.02	0.50
Kansas City	19400	118	0.03	20500.	0.00	0.03
Pueblo	5902	4.65	0.00	5931.	0.00	0.00
New Haven	7970	135	0.03	9761.	0.01	0.04
Cincinnati	- 13674	718	0.90	8951.	0.02	0.90
San Diego	94800	1920	0.94	1166.	0.05	0.95
Orlando	28000	544	0.82	197.	0.05	0.80
Dallas	140000	2750	0.81	1080.	0.05	0.80
Kenton Co.	7090	126	1.00	7.98	0.08	1.00
Seattle	22800	338	0.01	26600.	0.01	0.02
Phoenix	141000	2690	0.76	854.	0.06	0.81

* C = annual cost in $/year
b = constant
m = slope
t = calendar year.

+ C = annual cost in $/year
K = constant
b = rate of change
t = calendar year.

TABLE A-4. MAN-HOURS/MIL GAL VERSUS TIME

Utility	Linear* $C = b + mt$			Exponential+ $C = Ke^{bt}$		
	b	m	r^2	K	b	r^2
Fairfax Co.	- 37.39	0.88	0.24	2.01	0.04	0.20
Elizabethtown	30.22	- 0.23	0.46	44.28	0.03	0.20
Kansas City	77.70	0.48	0.03	96.04	- 0.01	0.03
Pueblo	14.74	0.39	0.04	22.10	0.01	0.04
New Haven	79.38	0.56	0.23	106.30	0.01	0.23
Cincinnati	88.14	0.83	0.86	200.35	0.03	0.85
San Diego	45.65	0.30	0.02	54.14	- 0.01	0.01
Orlando	39.48	0.03	0.00	38.01	- 0.00	0.00
Dallas	97.55	0.86	0.11	169.04	- 0.02	0.09
Kenton Co.	165.03	1.91	0.75	1849.39	- 0.06	0.77
Seattle	14.70	0.09	0.00	15.40	0.00	0.00
Phoenix	68.66	0.68	0.60	201.30	- 0.03	0.62

* C = annual cost in $/year
b = constant
m = slope
t = calendar year.

+ C = annual cost in $/year
K = constant
b = rate of change
t = calendar year.

TABLE A-5. DOLLARS/MAN-HOUR VERSUS TIME

Utility	Linear* $C = b + mt$			Exponential+ $C = Ke^{bt}$		
	b	m	r^2	K	b	r^2
Fairfax Co.	- 20.55	0.35	0.85	0.01	0.08	0.81
Elizabethtown	- 18.25	0.33	0.87	0.03	0.07	0.87
Kansas City	- 14.67	0.26	0.96	0.01	0.08	0.98
Pueblo	- 8.16	0.16	0.83	0.08	0.50	0.84
New Haven	- 20.94	0.35	0.97	0.01	0.09	0.96
Cincinnati	- 14.47	0.27	0.86	0.04	0.07	0.90
San Diego	- 20.17	0.35	0.78	0.01	0.08	0.86
Orlando	- 10.41	0.18	0.71	0.01	0.08	0.77
Dallas	- 10.91	0.19	0.85	0.00	0.10	0.74
Kenton Co.	- 7.19	0.16	0.34	0.20	0.04	0.34
Seattle	- 15.82	0.29	0.93	0.04	0.06	0.96
Phoenix	- 19.01	0.32	0.85	0.01	0.09	0.90

* C = annual cost in $/year
b = constant
m = slope
t = calendar year.

+ C = annual cost in $/year
K = constant
b = rate of change
t = calendar year.

TABLE A-6. ANNUAL SUPPORT SERVICES COSTS VERSUS TIME (Operating)

Utility	Linear* $C = b + mt$			Exponential+ $C = Ke^{bt}$		
	b	m	r^2	K	b	r^2
Fairfax Co.	- 9.99	159000	0.84	35.	0.15	0.73
Elizabethtown	-1.22×10^7	204000	0.93	1138.	0.11	0.96
Kansas City	-1.38×10^7	242000	0.86	6894.	0.09	0.82
Pueblo	-2.50×10^6	43200	0.91	1289.	0.08	0.95
New Haven	-9.09×10^6	153000	0.96	1173.	0.10	0.99
Cincinnati	-1.14×10^7	149000	0.93	2006.	0.10	0.94
San Diego	-1.78×10^7	296000	0.93	1404.	0.11	0.97
Orlando	-5.64×10^6	91500	0.92	52.	0.14	0.92
Dallas	-2.52×10^7	403000	0.93	65.	0.15	0.97
Kenton Co.	- 586000	10200	0.84	355.	0.08	0.87
Seattle	-1.87×10^7	317000	0.98	3688.	0.10	0.97
Phoenix	-2.14×10^7	360000	0.97	5704.	0.09	0.99

* C = annual cost in \$/year
b = constant
m = slope
t = calendar year.

+ C = annual cost in \$/year
K = constant
b = rate of change
t = calendar year.

TABLE A-7. ANNUAL ACQUISITION COSTS VERSUS TIME (Operating)

Utility	Linear* $C = b + mt$			Exponential+ $C = Ke^{bt}$		
	b	m	r^2	K	b	r^2
Fairfax Co.	-2.44×10^6	38200	0.63	4.7	0.15	0.67
Elizabethtown	-6.24×10^6	106000	0.86	638.	0.11	0.71
Kansas City	---	---	---	---	---	---
Pueblo	- 934000	14200	0.35	0.00	0.23	0.58
New Haven	- 592000	14200	0.76	32000.	0.04	0.77
Cincinnati	- 818000	18000	0.74	22700.	0.04	0.76
San Diego	-6.8×10^7	(1.1×10^6)	0.83	1136.	0.13	0.88
Orlando	---	---	---	---	---	---
Dallas	- 639000	17400	0.14	81000.	0.03	0.13
Kenton Co.	- 107000	1818	0.57	27.70	0.09	0.67
Seattle	-1.13×10^6	22000	0.61	7277.	0.06	0.61
Phoenix	-4.64×10^6	72000	0.95	1.03	0.18	0.88

* C = annual cost in $/year
b = constant
m = slope
t = calendar year.

+ C = annual cost in $/year
K - constant
b = rate of change
t = calendar year.

TABLE A-8. ANNUAL TREATMENT COST VERSUS TIME (Operating)

Utility	Linear* $C = b + mt$			Exponential+ $C = Ke^{bt}$		
	b	m	r^2	K	b	r^2
Fairfax Co.	- 771000	18800	0.32	44144	0.04	0.30
Elizabethtown	$- 3.43 \times 10^6$	58700	0.58	1515	0.09	0.66
Kansas City	$- 6.28 \times 10^6$	111000	0.94	6684	0.08	0.96
Pueblo	$- 1.29 \times 10^6$	24186	0.86	4839	0.06	0.92
New Haven	- 744000	14000	0.78	3300	0.06	0.70
Cincinnati	$- 1.8 \times 10^6$	41800	0.89	70700	0.04	0.91
San Diego	$- 3.4 \times 10^6$	59000	0.81	2135	0.08	0.85
Orlando	$- 4.5 \times 10^6$	73100	0.89	66	0.13	1.0
Dallas	$- 9.5 \times 10^6$	164000	0.90	5336	0.08	0.93
Kenton Co.	- 587000	10800	0.94	1584	0.07	0.97
Seattle	$- 2.9 \times 10^6$	47200	0.82	79	0.12	0.81
Phoenix	$- 7.3 \times 10^6$	121000	0.95	1138	0.10	0.93

* C = annual cost in $/year
b = constant
m = slope
t = calendar year.

+ C = annual cost in $/year
K = constant
b = rate of change
t = calendar year

TABLE A-9. ANNUAL POWER AND PUMPING COST VERSUS TIME (Operating)

Utility	Linear* $C = b + mt$ b	m	r^2	Exponential+ $C = Ke^{bt}$ K	b	r^2
Fairfax Co.	-2.5×10^6	42000	0.93	445	0.10	0.92
Elizabethtown	-8.6×10^6	143000	0.45	2202	0.09	0.61
Kansas City	-4.7×10^6	90000	0.96	24700	0.06	0.93
Pueblo	- 13500	6470	0.52	75900	0.02	0.53
New Haven	- 232000	6606	0.11	30800	0.03	0.11
Cincinnati	-3.7×10^6	74000	0.87	34000	0.05	0.89
San Diego	---	---	---	---	---	---
Orlando	---	---	---	---	---	---
Dallas	-6.3×10^6	110000	0.89	5299	0.08	0.92
Kenton Co.	---	---	---	---	---	---
Seattle	---	---	---	---	---	---
Phoenix	-9.1×10^6	151000	0.63	1910	0.09	0.61

* C = annual cost in $/year
b = constant
m = slope
t = calendar year.

+ C = annual cost in $/year
K = constant
b = rate of change
t = calendar year.

TABLE A-10. ANNUAL TRANSMISSION AND DISTRIBUTION COST VERSUS TIME
(Operating)

	Linear* $C = b + mt$			Exponential+ $C = Ke^{bt}$		
Utility	b	m	r^2	K	b	r^2
Fairfax Co.	-8.9×10^6	140000	0.77	37.9	0.14	0.83
Elizabethtown	-3.9×10^6	68400	0.91	4047.	0.08	0.94
Kansas City	-4.5×10^6	77600	0.89	1977.	0.09	0.87
Pueblo	-7.1×10^6	125700	0.79	8629.	0.07	0.89
New Haven	-2.7×10^6	50600	0.88	7729.	0.07	0.87
Cincinnati	-7.8×10^6	145000	0.97	17900.	0.07	0.96
San Diego	-4.7×10^6	101000	0.84	119000.	0.04	0.86
Orlando	-3.1×10^6	52800	0.70	740.	0.09	0.82
Dallas	-7.7×10^6	140000	0.89	15900.	0.07	0.91
Kenton Co.	- 648000	11100	0.91	257.	0.09	0.95
Seattle	-6.9×10^6	130000	0.83	29400.	0.06	0.82
Phoenix	-1.4×10^6	219000	0.95	164.	0.13	0.99

* C = annual cost in S/year
b = constant
m = slope
t = calendar year.

+ C = annual cost in $/year
K = constant
b = rate of change
t = calendar year.

TABLE A-11. ANNUAL TOTAL EXPENDITURES VERSUS TIME

Utility	Linear* $C = b + mt$			Exponential+ $C = Ke^{bt}$		
	b	m	r^2	K	b	r^2
Fairfax Co.	-7.28×10^7	1.15×10^6	0.63	0.57	0.23	0.58
Kansas City	-3.48×10^7	6.33×10^5	0.93	7×10^{-3}	4.95	0.91
Cincinnati	-3.75×10^7	6.76×10^5	0.63	2.44×10^4	0.086	0.46
Pueblo	-1.20×10^7	2.078×10^5	0.50	1.17×10^4	0.077	0.61
Dallas	-7.04×10^7	1.23×10^6	0.91	1×10^{-3}	5.61	0.96
Elizabethtown	-6.84×10^7	1.17×10^6	0.90	2.23×10^4	0.091	0.94
Kenton Co.	-2.53×10^6	4.48×10^4	0.80	3.16×10^3	0.075	0.90
Seattle	-3.32×10^7	6.13×10^5	0.97	9.41×10^4	0.066	0.98
Orlando	-1.86×10^7	3.13×10^5	0.86	2.90×10^3	0.10	0.94
San Diego	-8.94×10^7	1.54×10^6	0.88	4.04×10^4	0.087	0.92
New Haven	-4.67×10^7	7.97×10^5	0.95	9.13×10^3	0.098	0.96
Phoenix	-6.07×10^7	1.07×10^6	0.87	3×10^{-3}	5.24	0.94

* C = annual cost in \$/year
b = constant
m = slope
t = calendar year.

+ C = annual cost in \$/year
K = constant
b = rate of change
t = calendar year.

TABLE A-12. UNIT COSTS ($/mil gal)

Utility	Linear* $C = b + mt$			Exponential+ $C = Ke^{bt}$		
	b	m	r^2	K	b	r^2
Fairfax Co.	3.53×10^3	- 42.2	0.56	5.37×10^4	- 0.065	0.56
Kansas City	-1.18×10^3	21.8	0.93	3.14	0.067	0.91
Cincinnati	-3.29×10^3	8.55	0.95	26.9	0.033	0.95
Pueblo	-1.976×10^3	34.3	0.74	1.38	0.081	0.81
Dallas	-2.61×10^2	7.94	0.21	48.6	0.026	0.21
Elizabethtown	-1.46×10^3	26.4	0.92	2.66	0.071	0.93
Kenton Co.	3.87×10^2	0.59	0.00	397.	- 0.002	0.00
Seattle	-6.33×10^2	12.0	0.74	3.53	0.058	0.74
Orlando	-6.46×10^2	13.7	0.60	14.7	0.044	0.58
San Diego	-7.29×10^2	17.0	0.59	34.7	0.037	0.62
New Haven	-2.25×10^3	39.67	0.92	1.66	0.082	0.94
Phoenix	-9.46×10^1	5.68	0.41	79.7	0.019	0.40

* C = annual cost in $/year
b = constant
m = slope
t = calendar year.

\+ C = annual cost in $/year
b = constant
m = slope
t = calendar year.

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16. ABSTRACT

A Study of 12 selected water utilities was undertaken to determine the economics of water delivery. Data were collected from at least one Class A water utility (Revenues greater than $500,000/year) in each of the U.S. Environmental Protection Agency's 10 regions. These data are presented in a two volume report. Volume I provides summary information and in-depth analysis of the 12 utilities studied. All the uilities are analyzed in aggregate, and factors affecting the cost of water supply are examined. Also provided is an evaluation of the hypothetical impact of a proposed organic regulation, promulgated under the Safe Drinking Water Act, in 1980.

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